

BLM LIBRARY



88018823

Garrison Study Area Report



**RESOURCE & POTENTIAL
RECLAMATION EVALUATION**

Garrison Study Area Report
Published February 1983

The Federal Coal Management Program has been designed as an interagency cooperative effort to meet national energy objectives.

Garrison Study Area Report was prepared through the efforts of the U. S. Department of Interior, principally the Bureau of Land Management and Bureau of Reclamation. The study effort began in 1980 and was concluded in 1983 with the publication of this report.

The area described in this report has been tentatively determined to be a potential Federal coal development area. The purpose of this report is to provide information on the area's reclamation potential should coal development occur. This report will assist managers in making final Federal coal leasing decisions.

Editor's Note: In order to more closely associate the EMRIA program with the Federal Coal Management Program, the name "EMRIA" was officially dropped from use in May 1981. The responsibilities of the EMRIA program now come under "Technical Investigations in support of the Federal Coal Management Program."

Limited copies of this report are available from:

Bureau of Land Management
Montana State Office
Granite Tower
222 N. 32nd St.
P. O. Box 30157
Billings, MT 59107

Please reference the title and report number 37-80 when making a request for this report.

Bureau of Land Management
Library
Bldg. 50, Denver Federal Center
Denver, CO 80225

REPORT DOCUMENTATION PAGE		1. REPORT NO. YA-515-IA9-3	2.	3. Recipient's Accession No.	
4. Title and Subtitle Garrison Study Area - Resource and Potential Reclamation Evaluation				5. Report Date February 1983	
				6.	
7. Author(s) Glenn H. Westman and Lovell M. Parish, Editors				8. Performing Organization Rept. No. 37-80	
9. Performing Organization Name and Address Bureau of Reclamation Upper Missouri Regional Office P. O. Box 2553 Billings, Montana 59103				10. Project/Task/Work Unit No.	
				11. Contract(C) or Grant(G) No. (C) (G)	
				13. Type of Report & Period Covered Final; 80-83	
12. Sponsoring Organization Name and Address Bureau of Land Management Montana State Office P. O. Box 30157 Billings, Montana 59107				14.	
15. Supplementary Notes Prepared jointly by the Bureau of Land Management and Bureau of Reclamation					
16. Abstract (Limit: 200 words) The purpose of this investigation was to collect baseline data for establishing reclamation objectives and lease stipulations. The Garrison Study Area, located in west-central North Dakota, lies within the glaciated portion of the Great Plains Physiographic Province. The topography is characterized by gently rolling uplands with short, steep slopes along Douglas Creek and its tributaries. Climatic conditions are typified by cold winters, warm summers, and large variations in seasonal precipitation. The frost-free (>32°F.) growing season averages 125 days between mid-May and mid to late September. The Paleocene Tongue River and Sentinel Butte Members of the Fort Union Formation are the bedrock units cropping out or unconformably underlying Pleistocene (glacial drift) and Holocene (alluvium) deposits in the study area. Five distinct lignite zones were penetrated by USBR drilling investigations. Of these, only the Minter Zone and Garrison Creek Zones occur over an areal extent wide enough to be correlated. The Minter Zone contains 1 to 5 coalbeds with a combined coal thickness of 1 to 15 feet; the Garrison Creek Zone is divided into upper and lower beds ranging in coal thickness from 1.5 to 16 feet and 0 to 8 feet, respectively. Only 2 of 22 samples from 3 USBR core holes were rated suitable for use as supplemental plant media; the remaining samples contained moderate or high levels of exchangeable sodium and/or clay and, in 2 shale samples, an excessive level of molybdenum. This investigation was terminated after only 3 of 15 scheduled core holes were completed when preliminary data showed coal reserves in the study area to be less than originally believed.					
17. Document Analysis a. Descriptors 0510 Environmental Surveys 0807 Coal Deposits 1407 Reclamation b. Identifiers/Open-Ended Terms Evaluation of Reclamation Potential of Surface-Mined Land Garrison Lignite Deposits, Williston Basin, McLean County, North Dakota c. COSATI Field/Group					
18. Availability Statement Release unlimited NTIS Springfield, VA. 22161		19. Security Class (This Report) Unclassified		21. No. of Pages	
		20. Security Class (This Page) Unclassified		22. Price	

14-36
D88C18823

BLM LIBRARY
SC-324A, BLDG. 50
DENVER FEDERAL CENTER
PO BOX 25047
DENVER, CO 80225-0047
GARRISON STUDY AREA
MC LEAN COUNTY
NORTH DAKOTA

25
125
1657
C12

CONTENTS

	<u>PAGE</u>
Introduction -----	1
Purpose -----	1
Authority -----	1
Responsibility -----	1
Bureau of Land Management -----	1
Bureau of Reclamation -----	1
Location -----	2
Present Land Uses -----	2
Postmining Land Uses -----	2
Climate -----	3
Temperature -----	3
Precipitation -----	3
Other Climatic Factors -----	3
Effect of Climate on Revegetation -----	3
Physiography and Drainage -----	5
Geology -----	6
Regional Geology -----	6
Site Geology -----	6
Investigations -----	6
Stratigraphy -----	7

	<u>Page</u>
Paleocene -----	7
Pleistocene -----	8
Holocene -----	10
Lignite Beds -----	11
Structure -----	11
Paleontology -----	12
Mineral and Energy Resources -----	12
Engineering Geology -----	12
Stability of Excavation Slopes -----	12
Stability of the Present Landscape -----	12
Overburden Expansion -----	13
Instability of the Postmining Landscape -----	13
Material Sources -----	14
Impervious -----	14
Pervious -----	14
Concrete Aggregate -----	14
Riprap -----	14
Seismicity -----	14
Bedrock Suitability for Revegetation -----	16
Bibliography	
Appendix	

PLATES

	<u>Follows Page (Number) or Located in Appendix (A)</u>
Plate 1 - General Location Map -----	2
Plate 2 - Generalized Geologic Investigations Map -----	2
Plate 3 - Generalized Bedrock Geologic Map -----	6
Plate 4 - Geologic Log of DH80-101 -----	A
Plate 5 - Geologic Log of DH80-102 -----	A
Plate 6 - Geologic Log of DH80-103 -----	A

TABLES

Table 1 - Average Daily Maximum, Minimum, and Mean Temperatures -----	4
Table 2 - Average Monthly Precipitation, including Snowfall -----	4
Table 3 - Soil Analysis Data Sheet - Geologic Drill Hole DH80-101 -----	A
Table 4 - Soil Analysis Data Sheet - Geologic Drill Hole DH80-102 -----	A
Table 5 - Soil Analysis Data Sheet - Geologic Drill Hole DH80-103 -----	A
Table 6 - Criteria Used to Determine Suitability of Bedrock Material for Use as Plant Media in Revegetation -----	A
Table 7 - Suitability of Bedrock Material for Use as Plant Media in Revegetation -----	A

EXHIBITS

Exhibit 1 - Screenable Soil Characterization as Related to Land Reclamation -----	A
Exhibit 2 - Soils and Water Laboratory Procedures and References -----	A

RESOURCE AND POTENTIAL RECLAMATION EVALUATION
OF THE
GARRISON STUDY AREA
MC LEAN COUNTY
NORTH DAKOTA

INTRODUCTION

Recent energy shortages have forced our society to seek new domestic sources. Attention has focused on the immense quantities of low sulfur coal that lie within the Rocky Mountain and Northern Great Plains regions. The Department of the Interior, principally the Bureau of Land Management, is responsible for both assisting in meeting these energy demands and, at the same time, providing sound reclamation guidelines so that the disturbed lands are restored to an acceptable condition.

PURPOSE

The purpose of this report is to present data obtained from Bureau of Reclamation investigations in the Garrison Study Area.

AUTHORITY

This report is prepared in accordance with Section 4 of the agreement between the Bureau of Land Management and the Bureau of Reclamation dated May 7, 1974, and Work Order Number YA-515-IA9-3 dated January 22, 1979.

RESPONSIBILITY

BUREAU OF LAND MANAGEMENT

1. Selection of the study area.
2. Determination of the extent of the study.
3. Procurement of easements and rights-of-entry.

BUREAU OF RECLAMATION

1. Drilling a series of core holes through potential surface mineable coalbeds in the study area.
2. Evaluation of core materials for their suitability in a reconstructed profile.
3. Providing the Bureau of Land Management with a final report of all investigations.

LOCATION

The Garrison Study Area was originally planned to include parts of (1) Sections 4, 5, 6, 7, 8, 15, 17, 22, 28, 29, 30 and 32, T. 149 N., R. 84 W. (2) Sections 2, 13, 15, 24 and 27, T. 149 N., R. 85 W., and (3) Sections 30, 31, and 32, T. 150 N., R. 84 W. in McLean County, North Dakota. The study area would have been centered approximately five miles northwest of the town of Garrison (Plate 1).

After three core holes were completed, the Bureau of Land Management decided to terminate the Garrison project in favor of using the appropriated funds in other study areas. Reasons for the study termination were primarily: (1) a shift in priority; and (2) indication from preliminary drilling that the coal reserves in the Garrison Study Area are not as extensive as was originally believed.

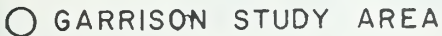
Plate 2 shows the locations of the fifteen core holes originally planned for the study area and the locations of the three core holes that were actually completed. This report is based on data derived from those completed holes.

PRESENT LAND USES

The study area is being used for livestock grazing and hay and grain production.

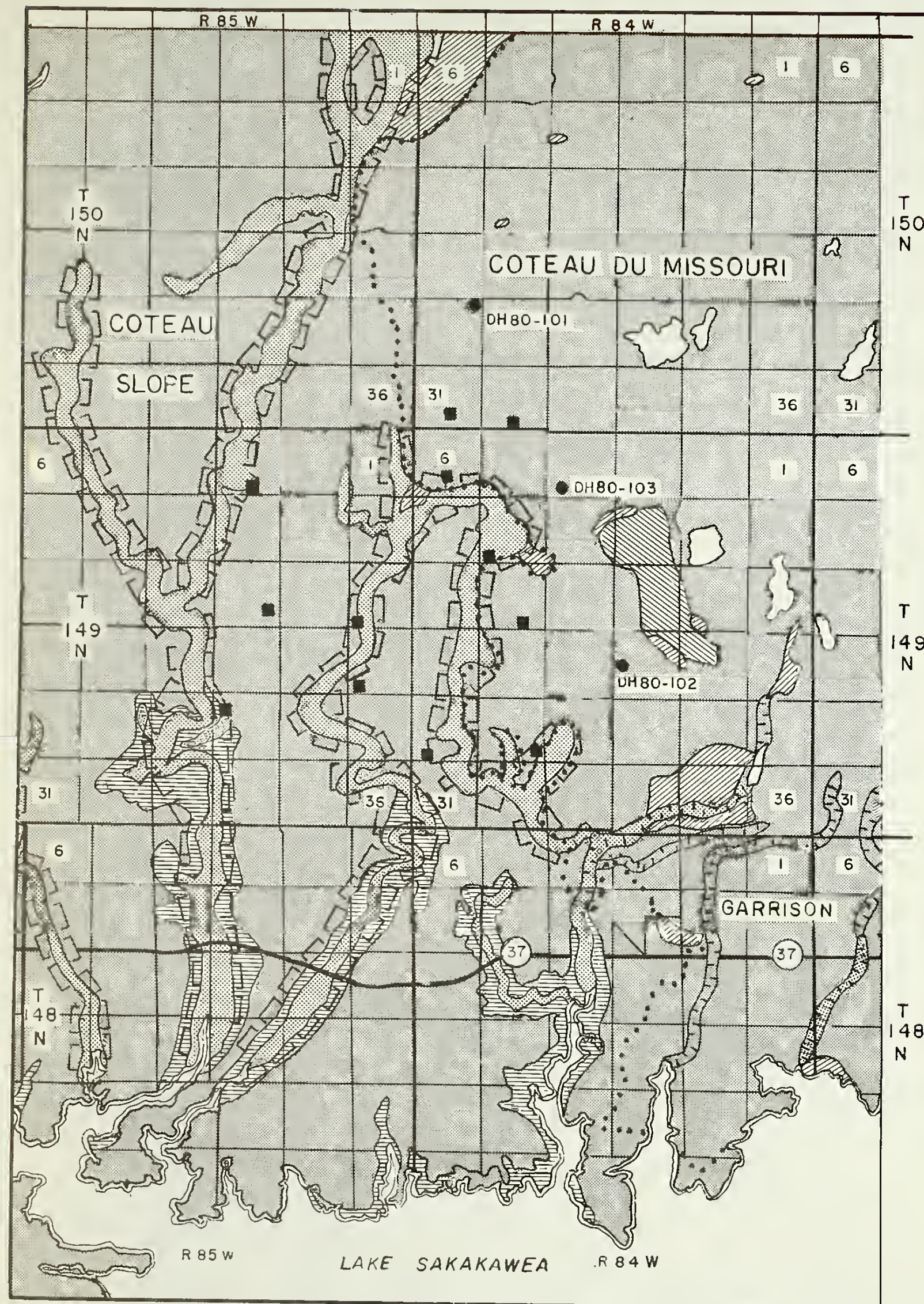
POSTMINING LAND USES

Postmining land uses are expected to be similar to the present uses.



DESIGNED V. LINSSEN SUBMITTED _____
DRAWN V. LINSSEN RECOMMENDED _____
CHECKED E. J. F. APPROVED _____

BILLINGS, MONTANA MARCH 1976 1305-600-301



HOLOCENE

PLEISTOCENE

PALEOCENE

EXPLANATION



ALLUVIUM - Unconsolidated deposits of dark brown, gray or black silty clay, clayey silt, clay or sandy silt and some gravel; vague horizontal bedding; oxidized; bones, shells, and wood common. Includes some slough deposits of soft, organic clay; bluish or greenish hues; vaguely bedded.



BOULDER-CLAY FACIES (GLACIAL TILL) - A relatively uniform nonbedded mixture of approximately equal parts sand, silt, and clay along with small percentages of gravel, cobbles, and boulders.



SAND AND GRAVEL FACIES (OUTWASH AND STREAM SEDIMENT) - Deposits consisting of sand, gravelly sand, sandy gravel, and some silty sand; some cross-bedding; poor to medium sorting; rude horizontal bedding. A small fraction is material that was deposited by glacial meltwater and most of the remainder is stream sediment deposited by water derived from local precipitation during and immediately following glaciation.



SILT AND CLAY FACIES (LACUSTRINE) - Lake deposits consisting of silty clay, clay, and clayey silt; horizontal bedding; oxidized; shells common.



FORT UNION FORMATION - Sandstone, siltstone, shale and lignite.



MELT-WATER TRENCHES - Trenches that carried glacial meltwater or runoff from pluvial precipitation. Modern stream erosion has modified these trenches in many instances.



PARTLY BURIED VALLEYS - Sags that may reflect the presence of buried meltwater trenches, preglacial valleys or pluvial trenches.



Approximate boundary between the Coteau du Missouri and the Coteau Slope.

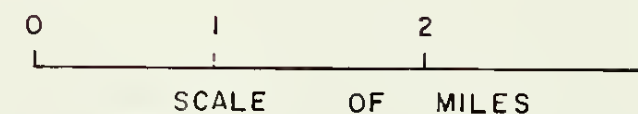


Bureau of Reclamation Drill Hole (completed).



Proposed Bureau of Reclamation Drill Hole (not completed).

NOTE: This drawing is based on Plate 1, "Geologic Map of McLean County, North Dakota" from North Dakota Geological Survey Bulletin 60 - Part 1, by John P. Bluemle, 1971. It has been modified to better fulfill the needs of this report.



ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GARRISON STUDY AREA- NO. DAKOTA
GENERALIZED GEOLOGIC
INVESTIGATION MAP

DESIGNED L. Parish FIELD APPROVAL _____
DRAWN I. G. Ling TECHNICAL APPROVAL _____
CHECKED _____ APPROVED _____

BILLINGS, MONTANA 8-31-82 1305-600-302

CLIMATE

The Garrison Study Area has a continental-type climate characterized by warm summers, harsh cold winters, and large variations in seasonal precipitation.

TEMPERATURE

A mean annual temperature of 40.6 °F. indicates little when considering the wide-ranging seasonal temperatures in this area. As shown in Table 1, average daily temperatures range from 7.2 °F. in January to 70.2 °F. in July.

In an average year, 17 days have a maximum temperature exceeding 90 °F. This occurs most frequently between late July and mid to late August. The probability of sub-zero temperatures occurring for 5 consecutive days is greatest (45-50%) in late January.

The average length of the frost-free (>32 °F.) growing season is 125 days between mid-May and mid to late September. However, native range plants and small grains usually deplete the available soil moisture by about mid-July and mature or become dormant.

PRECIPITATION

Warm, moist air masses from the Gulf of Mexico produce most of the precipitation in this area.

The average annual precipitation in the area is 16.37 inches. Of this amount, about 80 percent falls between April and September (see Table 2). June is typically the wettest month, averaging 3.68 inches. Snowfall, most common between early December and late March, often comprises about 16 percent of the annual precipitation.

OTHER CLIMATIC FACTORS

Thunderstorms occur on about 23 days in an average year, with July being the most susceptible month. The peak hail activity is in June, July, and August. Tornadoes also occur in this area.

Between November and early spring, winds blow primarily from the west. Southeasterly winds prevail during much of the remainder of the year. The average wind speed in the area is about 10 miles per hour.

EFFECT OF CLIMATE ON REVEGETATION

Most climatic factors in the Garrison Study Area appear conducive to revegetation of surface-mined land with native grasses/forbs or small grains. Spring is the most favorable time for planting, since soil moisture is relatively high during the early part of the growing season. With favorable moisture and temperature conditions, seedlings will grow rapidly and become established before the available soil moisture is depleted in about mid-July.

Several climatic factors that could adversely affect revegetation efforts in this study area include: (1) below normal or uneven distribution of precipitation, especially during the growing season, (2) severe thunderstorms, hailstorms, or tornadoes that cause crop damage and soil erosion, (3) late spring freezes, and (4) moisture depletion by wind.

Table 1 - Average Daily Maximum, Minimum, and Mean Temperatures -
Garrison Study Area, McLean County, North Dakota ^{1/}

<u>Month</u>	<u>Average Daily Maximum (°F.)</u>	<u>Average Daily Minimum (°F.)</u>	<u>Average Daily (°F.)</u>
January	17.3	-2.9	7.2
February	23.2	2.2	12.7
March	34.4	13.6	24.0
April	53.1	29.5	41.4
May	66.6	40.9	53.8
June	75.3	51.1	63.2
July	83.5	56.8	70.2
August	82.4	54.3	68.5
September	70.6	43.5	57.2
October	58.8	33.3	46.1
November	38.3	18.1	28.1
December	25.1	5.9	15.5
Year	52.4	28.8	40.6

Table 2 - Average Monthly Precipitation, Including Snowfall -
Garrison Study Area, McLean County, North Dakota ^{1/}

<u>Month</u>	<u>Average Precipitation (In.)</u>	<u>Average Snowfall (In)</u>
January	0.50	5.00
February	0.46	4.75
March	0.60	4.50
April	1.45	3.72
May	2.20	0.27
June	3.68	0.00
July	2.55	0.00
August	1.95	0.00
September	1.37	0.06
October	0.68	0.91
November	0.52	3.01
December	0.41	3.72
Year	16.37	25.94

^{1/} Data from Soil Survey of McLean County, North Dakota, Soil Conservation Service, 1979.

PHYSIOGRAPHY AND DRAINAGE

The Garrison Study Area lies in the glaciated portion of the Great Plains Physiographic Province. Topography of the area can generally be characterized as gently rolling uplands with short, steep slopes along Douglas Creek and its tributaries.

Maximum local relief is about 150 feet, varying from approximately 2050 feet in the northwestern part of the original study area to approximately 1,900 feet along Douglas Creek in the southeastern part of the area.

Drainage is southward to Lake Sakakawea and the Missouri River via Douglas and Garrison Creeks and their tributaries. Local upland areas have poorly developed drainage patterns with numerous potholes and sloughs.

GEOLOGY

REGIONAL GEOLOGY

The Garrison lignite deposits are located on the east side of the Williston Basin in west-central North Dakota. This basin, a part of the Great Plains Physiographic Province, is a synclinal structure extending from South Dakota into Canada, a distance of about 500 miles.

Since Precambrian time the geologic history of the area has included periods of deposition, deformation and erosion. A sequence of carbonates, sandstones, and shales, mostly of marine origin, was deposited throughout North Dakota during the Paleozoic and Mesozoic Eras. These sediments are about 14,000 feet thick in the deepest part of the Williston Basin, but thin rapidly eastward and are not present in the southeastern part of the State. Several unconformities exist throughout the Paleozoic and Mesozoic sequences in North Dakota, the most notable being the pre-Mesozoic erosional surface which truncates all Paleozoic sediments.

Deformation of the Rocky Mountains to the west and associated uplifting of the Great Plains area in North Dakota began with the Laramide Revolution at the close of Cretaceous time. Intermittent uplifting continued through the Paleocene and ended in Eocene time. By the middle of the Cenozoic Period materials eroded from the mountains were spread in thick sheets over most of the Great Plains. A second regional uplift occurred during Pliocene and Pleistocene times and elevated sediments to their present position. Streams rejuvenated by the last uplift have stripped Tertiary strata from the Great Plains and exhumed the buried mountains to the west.

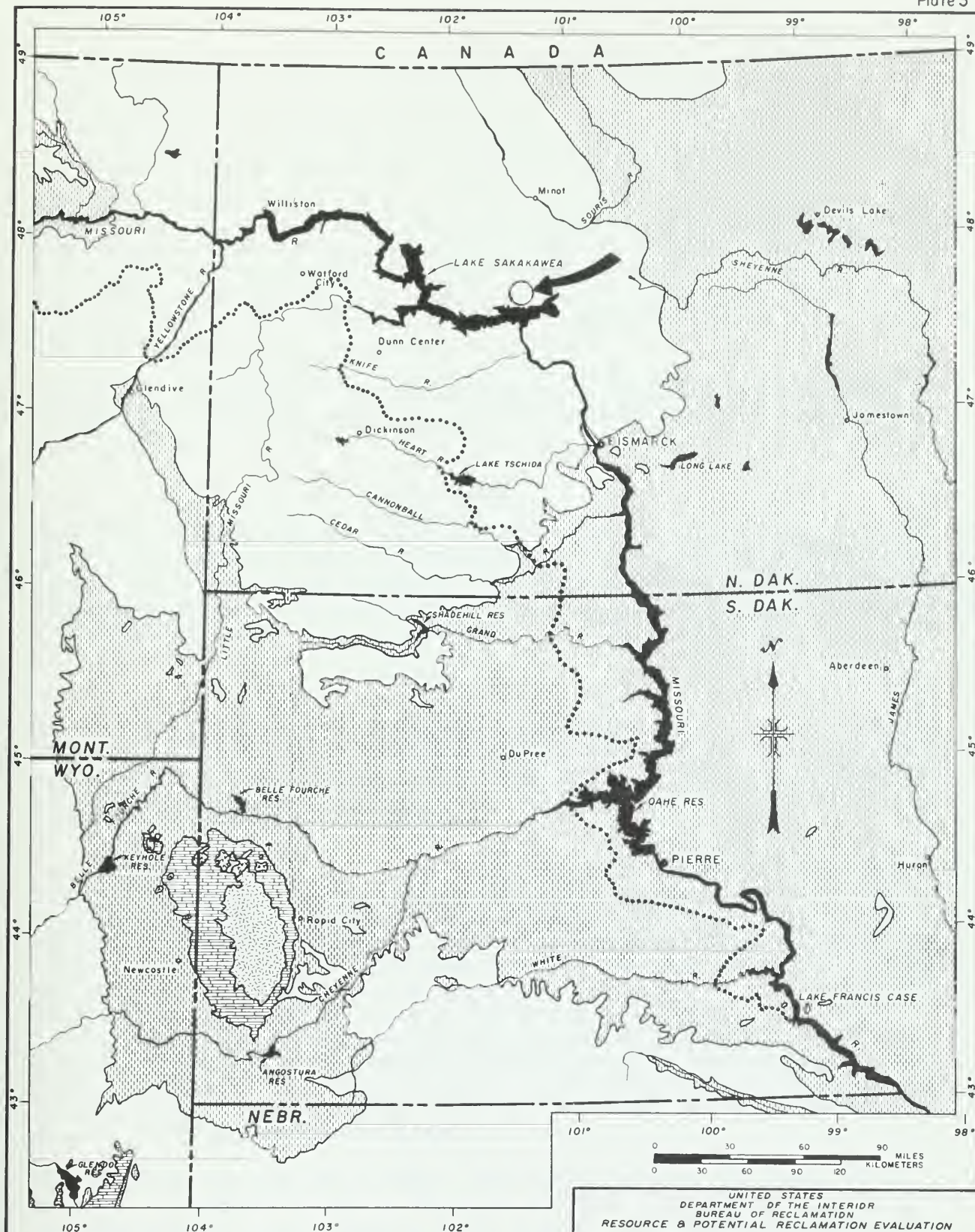
During the Pleistocene Epoch, several continental ice sheets invaded most of North Dakota. A sequence of till, outwash, and associated glacial debris was deposited during the advance and retreat of each ice sheet.

Today, shales, siltstones and sandstones of Cretaceous and Tertiary age cover the western part of North Dakota. Pleistocene and Holocene glacial, aeolian, and alluvial deposits mantle the bedrock in much of the area. Plate 3 is a generalized bedrock geologic map showing the southern limits of glaciation.

SITE GEOLOGY

Investigations

Previous geologic investigations in the Garrison area have proved invaluable in preparing this report. Two of the most useful references are: (1) North Dakota Geological Survey Bulletin 60 - Part 1, "Geology of Mc Lean County, North Dakota", by J. P. Bluemle, 1971; and (2) U. S. Geological Survey Open File Report 81-22, "Coal Geology of the Garrison Area, Mc Lean County, North Dakota", by Susan M. Cook, 1981. These and other pertinent references are listed in the Bibliography of this report.



- CENOZOIC
- CENOZOIC (IGNEOUS)
- MESOZOIC
- PALEOZOIC
- PRECAMBRIAN

--- SOUTHERN LIMITS OF GLACIATION

○ GARRISON STUDY AREA

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RESOURCE & POTENTIAL RECLAMATION EVALUATION
EMRIA STUDY AREAS
NORTH DAKOTA, SOUTH DAKOTA, MONTANA & WYOMING
**GENERALIZED
REGIONAL GEOLOGIC MAP**

DESIGNED BY V. LINSSEN
DRAWN BY V. LINSSEN
CHECKED BY G. J. T. APPROVED

BILLINGS, MONTANA MARCH 1976

1305-600-303

Geologic investigations for this report were conducted during January of 1980. Of the fifteen drill holes originally scheduled, three were completed by Bureau of Reclamation crews before the study was terminated. Those core holes ranged in depth from 134.5 to 204.5 feet. They were drilled with a Failing Model 1500 rotary drill using a Bx casing drive barrel in unconsolidated surficial material and an Hq wireline core barrel in the bedrock. Drill fluid consisted of water from local sources and an organic polymer - "Revert". All overburden core was tested for suitability in reconstructed profiles by Bureau of Reclamation Soils Laboratories in Bismarck, North Dakota and Denver, Colorado. Test results are graphically shown on the geologic logs (Plates 4 through 6 in the Appendix). Coal samples were collected and shipped to the U. S. Geological Survey Coal Resources Laboratory in Denver, Colorado. The samples were for their information and test results are not included in this report.

Plate 2 is a map showing where drill holes were completed by the Bureau of Reclamation. It also shows the generalized surface geology in and around the study area.

Stratigraphy

Stratigraphic units exposed in and near the study area range in age from Paleocene to Holocene. The Paleocene is represented by the Tongue River and Sentinel Butte Members of the Fort Union Formation. The Pleistocene is represented by three distinct facies based on composition. Recent deposition is primarily represented by Holocene alluvium. A brief description of each unit follows:

Paleocene

The Fort Union Formation is the bedrock unit cropping out or unconformably underlying glacial drift and alluvium in the Garrison Study Area. Two members are represented. They are the Tongue River Member (oldest) and the Sentinel Butte Member. The maximum thickness of the two members in the study area is probably somewhat less than 800 feet.

The Tongue River Member is a nonmarine sequence of sandstones, siltstones, shales, carbonaceous shales, and lignites with thin calcareous or siliceous cemented concretions. In general, the sandstones are fine grained and weakly cemented. Shales vary from soft, plastic clay-shale to moderately indurated claystone. Shale and siltstone zones readily break down and form slopes below sandstone ledges. Correlation of clastic sediments over even short distances is difficult due to facies changes, channeling, and variation in bedding thickness. Laboratory analyses of core samples indicate that chemical and physical properties of the bedrock usually cannot be projected between drill holes. Weathered exposures are usually light, buff-yellow to yellowish gray. Marcasite and/or pyrite nodules are found along zones of higher permeability, such as fractures and bedding planes.

The nonmarine Sentinel Butte Member conformably overlies the Tongue River Member. It consists of nearly identical units but usually has a light gray to brownish gray color. Bluemle (1971) states: "The single most important criterion for differentiating the Tongue River and Sentinel Butte is color.

In western North Dakota, oxidized exposures of the Tongue River have light, buff-yellow colors with considerable variations in texture and color between individual beds and, particularly when viewed from a distance, they present a bright overall aspect. In contrast, the Sentinel Butte beds are more gray and somber in color and rather uniform in both texture and color."

Because of the similarity of the two members, controversy surrounds the exact location of the contact between them. Cook (1981) states: "The contact between the Tongue River and Sentinel Butte is difficult to define in this area for two reasons: (1) Poor bedrock exposures, and (2) difficulty of correlating this area to an area with an accepted contact."

This problem with correlation has, thus, lead Bluemle to consider the major coalbeds in the study area part of the Sentinel Butte Member. Cook, however, uses Royse's (1967) definition of the Tongue River-Sentinel Butte contact which places the contact at the top of the Minter Coal Zone. That definition makes the major coalbeds part of the Tongue River Member.

Scoria or clinker beds are common in both the Tongue River and Sentinel Butte Members. They are fused or baked rock produced by the burning of lignite beds along and back from their outcrops. In places where heat was sufficiently intense, the clinker has been fused to a dark gray, lightweight rock similar in appearance to vesicular basalt. Near the outer edge of thermal metamorphism, the rock is disoriented and baked to a brick-red or almost orange color. Alteration of the overlying material is roughly proportional to the original thickness of lignite that has burned. The clinker is permeable and locally supplies water for springs and wells.

Pleistocene

Bluemle (1971) places the Pleistocene deposits of Mc Lean County (Garrison area included) in the Coleharbor Formation which he defines as: "... the lithostratigraphic unit that includes all bouldery, cobbly, pebbly, sandy, silty clay, sand and gravel, and silt and clay exposed in the type section and in all comparable sections. It is named for the town of Coleharbor in Mc Lean County, North Dakota". He defines the areal extent of the formation as covering most of the northeastern two-thirds of North Dakota, eastern South Dakota, Saskatchewan, Manitoba, northern Montana and western and southern Minnesota.

The formation covers approximately 95 percent of Mc Lean County. It is as much as 400 feet thick in some buried valleys, but only averages about 120 feet thick county-wide. Most of western Mc Lean County has a glacial cover of less than 50 feet thick.

Bluemle (1971) has divided the Coleharbor Formation into three separate facies based primarily on material size and type. These facies units are shown in a simplified form on Plate 2 and are chiefly described by him as:

Boulder-Clay Facies

This facies is, "... a relatively uniform, nonbedded mixture of approximately equal parts of sand, silt, and clay sized materials along with small percentages

of pebbles, cobbles, and boulders as much as a few feet in diameter.

The boulder-clay is generally dark gray below the ground-water table, grayish brown above the water table. Colors generally become darker downward from more to less highly oxidized zones Montmorillonite and other clay minerals along with small amounts of carbonates, quartz, and feldspars comprise the clay-sized fraction of the boulder-clay. The silt and sand fraction consists largely of quartz and feldspar with some carbonates, shale, and lignite. Pebbles are varied and consist of limestone, dolomite, various hard metamorphic and igneous rock types, shale, and lignite. Most of the cobbles and boulders are igneous and metamorphic rock types; a few are carbonates.

Because of its low permeability, the boulder-clay is generally not a satisfactory source of ground water. Any permeability that the boulder-clay has is due to vertical fracturing so that the permeability is greater vertically than horizontally.

The boulder-clay facies is mainly glacial till consisting of material eroded by the glaciers from areas north of Mc Lean County as well as locally. Part of the boulder-clay was subsequently deposited directly from the moving ice, and the remainder slid, slumped, and flowed to its present position when the ice finally melted."

The boulder-clay facies covers an estimated 75 percent of the surface area of Mc Lean County. Within the eastern part of the Garrison Study Area (Coteau Du Missouri) it is characterized as a dead-ice moraine noted for its hummocky topography with numerous kettles and nonintegrated drainage.

In the western part of the study area (Coteau Slope) the boulder-clay facies is generally characterized as sheet moraine consisting of a veneer of glacial drift overlying bedrock. It usually has a lower relief than the dead-ice moraine.

Sand and Gravel Facies

This facies includes those deposits ranging in composition from clean sandy gravel and gravelly sand to very dirty gravel and sand that occur both as, . . . "thin layers and lenses within the boulder-clay and as thick, continuous sequences independent of the boulder-clay.

The sand and gravel facies of the Coleharbor Formation has a mineralogic composition similar to the boulder-clay. The mineralogy indicates that it was ultimately derived from the northeast in Canada. The sand-sized fraction is largely quartz and feldspars with minor amounts of shale and carbonates. The gravel-sized fraction is largely granitic and metamorphic rock types, limestone, and dolomite. Some of the gravel has a high percentage of shale. Near the surface, caliche (CaCO_3) coats the undersides of pebbles and cobbles.

Generally the sand and gravel is loose, but in random local occurrences it is cemented with iron-oxide and forms conglomerate. . . . In areas where the sand and gravel is loose and uncemented, it is also highly permeable. The sand and gravel is generally the largest and most dependable source of high-quality groundwater in the county."

The sand and gravel facies contains deposits of several types. Some have large areal extent, for example outwash plains, while others such as terraces, channel fills, eskers, and kames cover a much smaller area. They may or may not contain inclusions of the other two Coleharbor Formation facies.

An estimated 20 percent of the surface of Mc Lean County is covered by the sand and gravel facies. It, . . . "was deposited mainly by rivers and streams during glacial times. Some of these rivers and streams must have been fed by meltwater from the glaciers, but probably large amounts of sand and gravel were deposited by non-glacial rivers 12,000 to 9,000 years ago when precipitation amounts were high and runoff was much greater than it is today. Some of the sand and gravel was deposited on beaches of lakes."

Silt and Clay Facies

This lacustrine facies consists of silt and clay deposits covering about 2 percent of the surface area of Mc Lean County. It can occur as either thin lenses in the other two facies or as thick units in buried valleys. Horizontal layering of fractions of an inch thickness is common in deposits of the facies. It is usually free of sand and larger particles.

Bluemle states, "The silt and sand facies has the same mineralogy as the silt and clay fraction of the boulder-clay: montmorillonite and other clay minerals, carbonates, quartz, and feldspars. Its permeability is about the same as the boulder-clay.

Where it is exposed at the surface, ... the silt-sized fraction is commonly prevalent over the clay, but there are numerous exceptions. The same is true to a lesser extent of the subsurface deposits. The silt and clay deposits are not at all uniform throughout Mc Lean County.

The Coleharbor silt and clay exposed at the surface in eastern Mc Lean County (Coteau Du Missouri) was deposited in lakes that were at least in part enclosed by glacial ice. Part of the surface silt and clay in western Mc Lean County (Coteau Slope) may have formed in the same way, but the remainder probably was deposited in natural lakes (not ice-walled) that would be in existence today if precipitation were greater. The subsurface silt and clay that is confined to buried valleys was probably deposited in large lakes that formed when easterly-flowing rivers were dammed by the advancing ice."

Holocene

Holocene deposits in the Garrison Study Area are predominantly alluvial sediment occurring along stream channels. They consist mainly of silt and clay (often organic) with minor amounts of sand and gravel. The deposits commonly exhibit thin horizontal layering and are very similar to underlying clay and silt units of the Coleharbor Formation. The presence of higher sand and organic contents usually identifies the alluvium.

Alluvial deposits range in thickness from a few feet along the smaller drainages

to over 100 feet beneath the Missouri River floodplain south of the Garrison Study Area.

Holocene age slough deposits are commonly found in the eastern part of the study area where interior drainage is sometimes locally prevalent. The bottoms of sloughs may contain tens of feet of dark brown to black organic clays eroded from the surrounding hillsides by runoff water. These deposits are of very limited areal extent and are not shown on Plate 2.

Windblown deposits of fine sand and silt are also fairly common where sand and gravel is exposed. They usually form low dunes or a thin surface cover of very limited extent. They also are not individually mapped.

Lignite Beds

Five distinct lignite beds or zones were penetrated by Bureau of Reclamation drilling in the Garrison Study Area. They appear to correlate fairly closely with nearby U. S. Geological Survey core hole logs contained in the 1981 report by Cook. None of the three Bureau holes encountered all five beds or zones.

From top to bottom the lignite beds or zones are: (1) Minter Zone; (2) local bed; (3) local bed; (4) Garrison Creek Zone; and (5) local bed. Of the five lignite beds only the Minter Zone and the Garrison Creek Zone contain units that occur over an areal extent wide enough to be useful in correlation. The three local beds are thin and cannot be mapped very far laterally.

Cook (1981) states that, " The Minter Zone consists of one to five coalbeds with a total coal thickness of 1 to 15 feet. Interburden between the Garrison Creek and Minter Zones ranges in thickness from 53 to 104 feet. In Tps. 149 and 150N., R. 84W., one bed of the Minter Zone is consistently greater than 5 feet thick and less than 100 feet deep.

The Garrison Creek Zone is divided into upper and lower beds -- the GC₁ and GC₂ beds, respectively. The GC₁ bed ranges in thickness from 1.5 to 16 feet. Thickness of the GC₂ bed ranges from 0 to 8 feet. Interburden between the GC₁ and GC₂ beds is from 16 to 73 feet thick. The Garrison Creek Zone was mined in the larger mines in the area, such as the Custer Creek and B&W mines."

The conclusion to the 1981 Cook report states, " Numerous discontinuous coal beds of restricted areal extent are present in the Garrison area. The most continuous beds are in the Garrison Creek and Minter Zones. Both zones are potentially valuable for future coal development because of the thickness of the beds under shallow overburden, the nearby transportation routes, and the availability of water."

Structure

The Garrison Study Area is in the eastern part of the Williston Basin. Local bedrock is essentially flat lying with a dip of less than 0.5 degree to the west. Slight local changes in dip indicate that some minor bedrock irregularities exist. No faulting has been mapped in the area.

Paleontology

Surface inspection did not reveal any significant or unusual paleontological sites. Fossils in the bedrock are obscured by the mantle of glacial drift. Those fossils commonly found in Fort Union drill core are calcareous shells and carbonaceous plant fragments. None were collected for identification.

Mineral and Energy Resources

Coal is the only proven mineral or energy resource in the Garrison Study Area. Extensive oil and gas investigations in the Williston Basin farther to the west may eventually extend into the area and provide local production.

ENGINEERING GEOLOGY

Stability of Excavation Slopes

Engineering property tests were not conducted on bedrock samples from the Garrison Study Area. The bedrock is somewhat softer, but physical property test results should be similar to those of Fort Union Formation samples tested at the Otter Creek Study Site, Montana (EMRIA Report No. 1).

Much of the bedrock at the Garrison Study Area consists of bentonitic shales which are susceptible to minor shrinking and swelling. Shear strengths of the material are low, especially in a saturated condition. Slides could easily develop adjacent to high walls in surface mines, particularly along beds of weak, plastic, carbonaceous shales which are typically cut by inherent slickensides. Adequate drainage will have to be maintained to relieve pore water pressure in the overburden as mine excavations progress.

Saturated, uncemented siltstones and fine grained sandstones will readily erode and flow into excavations. This problem is sometimes encountered in drilling when the walls of holes collapse or slough. Depth of excavation will be limited by the water table until these materials are dewatered.

Excavation slopes will vary considerably between mine sites and will be dependent on exposure time, moisture conditions, material types and depth of cut. Detailed engineering studies of the overburden will be required at each location for use in determination of designed slopes.

Studies conducted at the Otter Creek site indicate that disturbed overburden (spoil banks and piles) should have slopes not greater than 4 to 1 with berms of 50 to 100 feet in width designed on the slope surface.

Stability of the Present Landscape

In its present undisturbed state, the Garrison Study Area experiences no problems with land stability. Landslides do not occur because of the gentle slopes and subsidence is not a problem.

Overburden Expansion

Overburden volumes expand as the materials are broken up during mining. The increase in volume (bulking or swell) differs for various types of soil and rock. Soft sandstones and shales in the Fort Union Formation will probably expand about 25 percent. In some cases, the surface of the replaced overburden will be higher after mining than the ground surface was before disturbance.

Instability of the Postmining Landscape 1/

Three types of instability are common on reclaimed coal mined areas in the Northern Great Plains. They are: (1) area-wide settling; (2) localized collapse; and (3) piping. Each type of instability is affected by variables in the postmining landscape. These include the physical and chemical characteristics of the overburden, methods and equipment used in stripping and contouring operations, and the season when these activities occur.

Area-wide settling is common in most postmining landscapes, but appears to cause only minimal disruption. This settlement will generally be most pronounced during the first year and will continue at a decreasing rate with the progression of time.

The texture of the overburden will have a marked influence on settlement. Fine-textured (clayey) overburden usually results in more blocky and, initially, more porous spoils than does coarse-textured (sandy) overburden. Therefore, a lesser degree of settlement is expected in areas of largely sandy spoils than in areas of clayey spoils.

Equipment is also a critical factor. Settlement is significantly less in scraper-contoured areas than in dozer-contoured areas, especially if contouring is conducted in mid-winter. This is because a greater degree of compaction is achieved in scraper-contouring operations than in dozer-contouring operations.

Local collapse features develop soon after contouring and usually complete development within a year. They commonly occur in precontouring valley areas where frozen spoil blocks are concentrated by final, mid-winter dozer contouring. Thawing of these blocks results in local surface subsidence. In contrast, areas contoured in mid-winter with a scraper are stable because large blocks of frozen spoil are broken apart, spread, and compacted. This type of landscape instability is, therefore, largely equipment and seasonally controlled.

Piping appears to be a severe and long term problem in some postmining landscapes. Development usually begins soon after contouring and may continue for several years. In some postmining landscapes, piping has only started to develop after as much as 5 years of apparent stability. It is controlled by a combination of physical and chemical conditions in the spoils.

A key factor in the development of piping features is the cracking of spoils in areas containing highly dispersive sodic material. These cracks allow

1/ Groenewold, G. H., and Rehm, B. W., 1980

access for large volumes of surface runoff to flow into the subsurface. Piping generally develops on nearly flat slopes where surface runoff is minimal and infiltration is maximized.

Piping, like the other instability problems, most commonly develops in areas contoured by dozers. Scraper-contoured areas generally are better compacted, thus providing fewer subsurface avenues for infiltration of surface water.

Material Sources

Earth materials suitable for most construction can be found within or near the Garrison Study Area. Material types and the local sources are noted below:

Impervious

Impervious material is clayey or silty borrow that can be used for construction of embankments or as canal or ditch lining. It is available from the glacial till that covers most of the uplands.

Pervious

Pervious material is clean sand or gravel suitable for use in filters or other types of structures where free drainage is required. It can probably be found in the Pleistocene channel fill of the meltwater trenches shown on Plate 2, or from the areas of sand and gravel facies shown on the same plate.

Concrete Aggregate

Concrete aggregate is a clean sand and gravel similar to the pervious material described before. It may also be available from the same sources, but the nearest Bureau of Reclamation approved sources are located near the Missouri River approximately 25 to 30 miles southeast of the study area.

Riprap

Riprap is a durable, reasonably well-graded mixture of rock fragments generally ranging from about 6 inches to 3 feet in diameter. It is used for surface protection from running water. Ideally, individual fragments should be angular to remain stable on steep slopes. High quality riprap material is not available in the Garrison Study Area. The bedrock is too soft, and although there are scattered glacial boulders in the area, gathering them would be very expensive and they are too rounded to remain stable on anything but gentle slopes. Probably the closest sources of suitable rock are the Black Hills of South Dakota or the granitic basement rocks of extreme eastern North Dakota.

Seismicity

The Garrison Study Area lies within a relatively stable part of North America. All of North Dakota is within Zone 1 of the Algermissen Seismic Risk Map. In this zone, distant earthquakes can cause minor damage to structures with fundamental periods greater than 1.0 second (corresponds to Intensities V and VI of the Modified Mercalli Intensity Scale of 1931).

No earthquakes of intensity V or above (Modified Mercalli) have occurred within North Dakota during historical times. Earthquakes centered in Iowa, Minnesota, Montana, Nebraska, and Canada have been felt in the state. A list of earthquakes

that have been recorded in North Dakota follows, but much of the information on exact location and intensity is unknown:

DATE	Intensity (Modified Mercalli)	Distance from Garrison	Located Near
Oct. 9, 1872	Unknown	420 miles	Sioux City, Ia
Nov. 15, 1877	Unknown	Unknown	Iowa or Nebraska
May 15, 1909	Unknown	Unknown	SK, Canada
Oct. 26, 1946	IV	105 miles	Williston, ND
Aug. 17, 1959	IX	500 miles	Hebgen Lake, Mt
July 8, 1968	IV	90 miles	Huff, ND
July 9, 1975	Unknown	295 miles	Morris, MN

BEDROCK SUITABILITY FOR REVEGETATION

A systematic evaluation was made of the bedrock core materials described in Plates 4 through 6, Appendix, in order to determine suitability of the materials for use as supplemental revegetative media.

Screenable laboratory analyses, Exhibit 1, Appendix, as well as selected trace element determinations, were performed on the core samples using the procedures listed in Exhibit 2, Appendix. The results of the laboratory analyses are included in Tables 3, 4, and 5 in the Appendix.

The suitability criteria listed in Table 6, Appendix, were applied to the laboratory data in order to place the bedrock materials into one of three categories: Suitable, Limited Suitability, or Unsuitable.

Table 7, Appendix, presents a summary of bedrock suitability for revegetation in the Garrison Study Area. Deficiencies are indicated for the materials classified as Limited Suitability or Unsuitable. Overall, 8.8 percent of the bedrock materials were rated Suitable for use as supplemental plant media; 60.6 percent were of Limited Suitability, and 30.6 percent were Unsuitable.

Only two samples, both from DH 80-102, were rated Suitable for use as supplemental plant media. These samples were medium-textured, nonsaline, nonsodic, and permeable. The remaining samples were classified as Limited Suitability or Unsuitable due to high levels of exchangeable sodium, high clay percentage, and/or, in two shale samples, an excessive level of molybdenum.

Because the type and quality of the bedrock materials are highly diverse in the Garrison Study Area, the physical and chemical characteristics important to their use as plant media cannot be projected accurately between drill holes or to adjacent areas. Therefore, this bedrock suitability evaluation is applicable only to the specific site where each core was drilled. A more intensive drilling and analyzing program will be necessary prior to mining to accurately determine the quantity and quality of the bedrock materials in this study area.

BIBLIOGRAPHY

Bluemle, J. P., 1971, Geology of Mc Lean County, North Dakota:
North Dakota Geological Survey Bulletin 60-Part 1.

Cook, Susan M., 1981, Coal Geology of the Garrison Area, Mc Lean
County, North Dakota: U. S. Geological Survey Open File Report
81-22.

Groenewold, G. H., and Rehm, B. W., 1980, Instability of Contoured
Surface - Mined Landscapes in the Northern Great Plains: Causes
and Implications, 15 pp.

United States Bureau of Reclamation, 1968, Region 6 Concrete Aggregate
and Riprap Sources: Report No. C-1078-6A.

United States Department of the Interior, Bureau of Land Management,
1975, Otter Creek Study Site: EMRIA Report No. 1.

United States Department of the Interior, Bureau of Land Management,
1977, Guidelines for Reclamation Study Areas, EMRIA Handbook.

United States Department of the Interior, Bureau of Land Management,
1981, North Beulah Study Area: EMRIA Report No. 29.

APPENDIX

FEATURE GARRISON STUDY AREA PROJECT EMRIA STATE NORTH DAKOTA
HOLE NO. DH80-101 LOCATION 40Q' W. & 17Q' S. OF N.E. CORNER;
SEC. 30, T. 15Q N.R. 84 W. GROUND ELEV. 2055.0' ± DIP (ANGLE FROM HORIZ.) VERTICAL
BEGUN 1-14-80 FINISHED 1-15-80 DEPTH OF OVERBURDEN TOTAL DEPTH 134.5' BEARING

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED. SEE NOTES LOGGED BY R. WYBORNEY LOG REVIEWED BY PARISH

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	SOILS ANALYSIS SAMPLE		SUITABILITY FOR RECONSTRUCTED PROFILE			ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET)		SUITABLE	LIMITED SUITABILITY	UNSUITABLE					
			FROM	TO								
DRILL Failing 1500 truck-mounted. DRILLER Water and Power; R.V. Shaw METHOD Bx drive sample 0.0-11.0', 34.5-75.0', Hq wireline 11.0-34.5', 75.0-134.5'. Clear water used as drill fluid. DRILL FLUID LOSS Depth % Loss 0.0-20.0' 0 20.0-34.0' 75 34.0-60.0' 0 60.0-134.5' 55 CASING RECORD 0.0-3.5' 6" Cs WATER LEVEL DATA Date Depth of 1980 Hole Cs H ₂ O 1-15 60.0' 3.5' 42.0' HOLE COMPLETION Pulled casing from hole and backfilled with concrete CHARACTER OF DRILLING Drive samples taken when couldn't get recovery from Hq wireline. Necessary to ream hole with 4" bit after every 10' run.	Bx 90 10 88 Hq #1 10.0 18.0 43 20 90 #2 18.0 43.0 30 30 Bx 40 90 0' 60 50 60 80 #3 43.0 65.0 90 80 #4 65.0 71.1 70 100 100 Hq 100 80 100 #5 71.1 96.0 90 100 #6 96.0 121.0						2055.0 0.0 10 20 30 40 50 60 70 80 90 100 110 120 130 140				GLACIAL TILL-PLEISTOCENE 0-18.0' SANDY CLAY: about 60% low plasticity fines; 30% fine to coarse grained sand; 10% 1/4" to 1/2" subangular to subrounded gravel; weathered throughout; some iron oxide and caliche; strong HCl reaction; brown. (CL) 18.0-71.1' SANDY CLAY: about 55% medium to high plasticity fines; 30% fine to coarse grained sand; 15% 1/4" to 1/2" subrounded gravel; weathered; slight HCl reaction; brown. (CL-CH) FORT UNION FORMATION-PALEOCENE 71.1-134.5' SHALE: Intermittent sand, carbonaceous, and coal seams; unweathered, thin laminations (fissile) visible; no visible jointing; all breaks mechanical; soft, can be indented by slight finger pressure; moist; gray brown, nonreactive to HCl; max. core length 1.3'. Sand seam 87.8-88.9' Carbonaceous at 77.8-78.2', 83.0-84.5', 97.1-97.7', 114.5-115.0' Coal at 78.2-79.5', 91.7-94.2', 100.5-107.7'. MINTER ZONE 1963.3 91.7 1960.8 94.2	

EXPLANATION

CORE LOSS

CORE RECOVERY

Type of hole D = Diamond, H = Hoystellite, S = Shot, C = Churn
Hole sealed P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

DEPTH AND ELEV. OF WATER
LEVEL AND DATE MEASURED. SEE NOTES LOGGED BY . . . R. WYBORNEY LOG REVIEWED BY . . . PARISH

EXPLANATION

Type of hole D = Diamond, H = Hoystellite, S = Shot, C = Churn
Hole sealed P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . . Ex = 1-3/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

Study Area: Carrison, North Dakota

Location. Sec. 30 Twp. 150 N Range 84 W

Relief: Stoniness: Parent Material:

Elevation: Soil Series:

Slope Aspect: Drainage: Soil Classification:

Vegetation: Ground Water:

Erosion: Land Form: Profile Description By: Date:

DETERMINATION		DATA (mg/l)							DETERMINATION		LABORATORY DESCRIPTION					
Laboratory Number		19,683	19,684	19,685	19,686	19,687	19,688		Laboratory Number		01	02	03	04	05	06
Depth	(ft)	10.0 - 18.0	18.0 - 43.0	43.0- 65.0	65.0 - 71.1	71.1 - 96.0	96.0 - 121.0		DEPTH	(Ft)	10.0-18.0	18.0-43.0	43.0-65.0	65.0-71.1	71.1-96.0	96.0-121.0
ALUMINUM	Al								PARTICLE SIZE ANALYSIS	(percent)						
									Very Coarse Sand	(2.0-1.0 mm)						
SILVER	Ag								Coarse Sand	(1.0-0.5 mm)						
ARSENIC	As								Medium Sand	(0.5-0.25 mm)						
									Fine Sand	(0.25-0.10 mm)						
BORON	B	0.5	0.8	1.4	1.0	1.2	1.0		Very Fine Sand	(0.10-0.05 mm)						
									TOTAL SAND	(2.0-0.05 mm)						
BARIUM	Ba								SILT	(0.05-0.002 mm)						
BERYLLIUM	Be								CLAY	(0.002 mm)						
CADMIUM	Cd								TEXTURAL CLASS (LAB)	(g/cm ³)						
COBALT	Co								BULK DENSITY	(in/hr)						
CHROMIUM	Cr								HYDRAULIC CONDUCTIVITY							
COPPER	Cu	3.4	3.8	6.4	14.0	24.0	18.0		6th Hr.		0.28	0.12	0.00	0.00	0.00	0.00
IRON	Fe								24th Hr.		0.32	0.15	0.00	0.00	0.00	0.00
MERCURY	Hg								SETTLING VOLUME	(ml)	23	23	22	24	34	30
LITHIUM	Li								MOISTURE RETENTION	(percent)						
MANCANESE	Mn								1/10 bar							
									1/3 bar							
MOLYBDENUM	Mo	0.41	0.34	0.27	0.67	1.30	0.93		15 bar		14.7	14.2	13.9	14.5	23.3	20.1
NICKEL	Ni								SOIL REACTION-PH							
PHOSPHOROUS	P								Paste							
LEAD	Pb								1:5 H ₂ O		7.2	7.4	7.4	7.6	7.8	8.1
									1:2 0.01 N CaCl ₂		5.9	6.2	6.3	6.4	6.5	6.9
STRONTIUM	Sr								ORGANIC CARBON	(percent)						
SELENIUM	Se	0.0187	0.0045	0.0167	0.0061	0.0064	0.0014		AVAILABLE PHOSPHORUS	(ppm)						
SULFUR	S	750.0	630.0	500.0	350.0	350.0	100.0		Ca CO ₃ EQUIVALENT	(percent)						
									CYPSUM REQUIREMENT	(me/100g)						
ZINC	Zn								SATURATION EXTRACT							
									Saturation Percentage							
									EC@ 25 °C	*	1.94	1.42	1.41	1.76	1.99	1.78
									Ca++	(mmhos/cm)						
									Mg++	(me/l)						
									Na+	(me/l)						
									K+	(me/l)						
									CO ₃ -	(me/l)						
									HCO ₃ -	(me/l)						
									Cl-	(me/l)						
									SO ₄ -	(me/l)						
									NO ₃ -	(me/l)						
									SAR	(me/l)						
									Na	(me/100g)						
									Ca++	(me/100g)						
									1:5 EXTRACT	(mmhos/cm)	0.583	0.426	0.424	0.530	0.598	0.536
									FC ₂ @ 25°C	(me/l)						
									Ca++	(percent)						
									EXCHANGEABLE SODIUM							
									ACIDITY							
									IN KCL exchange acidity							
									- Total							
									Al+++		15.8	21.2	14.6	21.6	38.0	25.4
									CATION EXCHANGE CAPACITY							
									NaOAc@pH 8.2							
									BORON	(me/l)						

* Estimated value using 3.33 x the value for 1.5 extract

Study Area: Garrison, North Dakota Relief: _____ Stoniness: _____ Parent Material: _____
Location. Sec. 30 Twp. 130 N Range 84 W Elevation: _____ Soil Series: _____
Slope Aspect: _____ Drainage: _____ Soil Classification: _____
Vegetation: _____ Ground Water: _____
Erosion: _____ Land Form: _____ Profile Description By: _____ Date: _____

DETERMINATION		DATA	LABORATORY DESCRIPTION	DATA
Laboratory Number		(mg/l)	Determination	
19,689			Laboratory Number	07
Depth	(ft)	121.0 - 134.5	DEPTH	(Ft)
ALUMINUM	Al		PARTICLE SIZE ANALYSIS	(percent)
SILVER	Ag		Very Coarse Sand	(2.0-1.0 mm)
ARSENIC	As		Coarse Sand	(1.0-0.5 mm)
BORON	B	0.7	Medium Sand	(0.5-0.25 mm)
BARIUM	Ba		Fine Sand	(0.25-0.10 mm)
BERYLLIUM	Be		Very Fine Sand	(0.10-0.05 mm)
CADMIUM	Cd		TOTAL SAND	(2.0-0.05 mm)
COPPER	Cu	12.0	SILT	(0.05-0.002 mm)
IRON	Fe		CLAY	(0.002 mm)
MERCURY	Hg		TEXTURAL CLASS (LAB)	
LITHIUM	Li		BULK DENSITY	(g/cm ³)
MANGANESE	Mn		HYDRAULIC CONDUCTIVITY	(in/hr)
MOLYBDENUM	Mo		6th Hr.	
NICKEL	Ni		SETTLING VOLUME	(ml)
PHOSPHOROUS	P		MOISTURE RETENTION	(percent)
LEAD	Pb		1/10 bar	
STRONTIUM	Sr		1/3 bar	
SELENIUM	Se	0.0606	SOIL REACTION-pH	
SULFUR	S	115.0	Paste	
ZINC	Zn		1:5 H ₂ O	
			1:2 0.01 M CaCl ₂	
			ORGANIC CARBON	(percent)
			AVAILABLE PHOSPHORUS	(ppm)
			Ca CO ₃ EQUIVALENT	(percent)
			GYPSUM REQUIREMENT	(me/100g)
			SATURATION EXTRACT	
			Saturation Percentage	*
			EC _e @ 25 °C	(mmhos/cm)
			Ca++	(me/l)
			Hg++	(me/l)
			Na+	(me/l)
			K+	(me/l)
			CO ₃ -	(me/l)
			HCO ₃ -	(me/l)
			Cl-	(me/l)
			SO ₄ -	(me/l)
			NO ₃ -	(me/l)
			SAR	(me/l)
			Na	(me/100g)
			Ca+Hg	(me/100g)
			1:5 EXTRACT	
			FC@ 25 °C	(mmhos/cm)
			Ca+Hg	(me/l)
			EXCHANGEABLE SODIUM	(percent)
			ACIDITY	
			IN KCL exchange acidity	
			Total	(me/100g)
			Al+++	(me/100g)
			CATION EXCHANGE CAPACITY	(me/100g)
			NaOAc@pH 8.2	
			BORON	(me/l)

* Estimated value using 3.33 x the value for 1:5 extract

GEOLOGIC DRILL HOLE 80-102

Study Area: Garrison, North Dakota Relief: _____ Stoniness: _____ Parent Material: _____
Location. Sec. 22 Twp. 149 N Range 84 W Elevation: _____ Soil Series: _____
Slope Aspect: _____ Drainage: _____ Soil Classification: _____
Climate: _____ Ground Water: _____
Land Use: _____ Erosion: _____ Land Form: _____ Profile Description By: _____ Date: _____

DETERMINATION		DATA					LABORATORY DESCRIPTION		DATA						
Laboratory Number		19,690	19,691	19,692	19,693	19,694	19,695	Laboratory Number		08	09	10	11	12	13
Depth (Ft)		10.0 - 35.0	35.0 - 54.7	54.7 - 71.5	71.5 - 96.0	96.0 - 121.0	121.0 - 134.5	DEPTH	(Ft)	10.0-35.0	35.0-54.7	54.7-71.5	71.5-96.0	96.0-121.0	121.0-134.5
ALUMINUM	Al							PARTICLE SIZE ANALYSIS	(percent)						
SILVER	Ag							Very Coarse Sand	(2.0-1.0 mm)						
ARSENIC	As							Coarse Sand	(1.0-0.5 mm)						
								Medium Sand	(0.5-0.25 mm)						
								Fine Sand	(0.25-0.10 mm)						
								Very Fine Sand	(0.10-0.05 mm)						
BORON	B	0.5	1.7	0.9	0.5	0.5	0.7	TOTAL SAND	(2.0-0.05 mm)						
BARIUM	Ba							SILT	(0.05-0.002 mm)						
								CLAY	(0.002 mm)						
BERYLLIUM	Be							TEXTURAL CLASS (LAB)							
								BULK DENSITY	(g/cm ³)						
								HYDRAULIC CONDUCTIVITY	(in/hr)						
CADMIUM	Cd							6th Hr.		0.07	0.08	0.00	0.00	0.00	0.00
COBALT	Co							24th Hr.		0.07	0.09	0.00	0.00	0.00	0.00
								SETTLING VOLUME	(ml)	24	24	27	44	84	52
								MOISTURE RETENTION	(percent)						
CHROMIUM	Cr							1/10 bar							
COPPER	Cu	3.2	7.2	13.0	7.6	9.6	16.0	1/3 bar		13.5	14.3	14.6	27.7	41.8	33.2
IRON	Fe							SOIL REACTION-pH							
MERCURY	Hg							Paste							
								1:5 H ₂ O							
LITHIUM	Li							1:2 0.01 M CaCl ₂							
MANGANESE	Mn							ORGANIC CARBON	(percent)						
								AVAILABLE PHOSPHORUS	(ppm)						
								Ca CO ₃ EQUIVALENT	(percent)						
								GYPNUM REQUIREMENT	(me/100g)						
								SATURATION EXTRACT							
MOLYBDENUM	Mo	0.34	0.43	1.0	0.55	0.2	0.86	Saturation Percentage							
NICKEL	Ni							EC@ 25 °C	(mmhos/cm)	2.66	1.49	1.12	1.64	1.48	1.61
PHOSPHOROUS	P							Ca++	(me/l)						
								Mg++	(me/l)						
LEAD	Pb							Na+	(me/l)						
								K+	(me/l)						
STRONTIUM	Sr							CO ₃ -	(me/l)						
SELENIUM	Se							HCO ₃ -	(me/l)						
								Cl-	(me/l)						
								SO ₄ -	(me/l)						
								NO ₃ -	(me/l)						
SULFUR	S	880.0	310.0	83.0	53.0	100.0	150.0	SAR	(me/l)						
ZINC	Zn							Na	(me/l)						
								Ca+Hg	(me/100g)						
								1:5 EXTRACT	(mmhos/cm)	0.799	0.448	0.338	0.493	0.445	0.483
								FC@ 25 °C	(me/l)						
								Ca+Hg	(me/l)						
								EXCHANGEABLE SODIUM	(percent)						
								ACIDITY							
								IN KCL exchange acidity							
								- Total							
								Al+++	(me/100g)						
								CATION EXCHANGE CAPACITY	(me/100g)	17.8	11.8	27.8	27.2	23.0	19.4
								NaOAc@pH 8.2	(me/100g)						
								BORON	(mg/l)						

* Estimated value using 3.33 x the value for 1:5 extract

GEOLOGIC DRILL HOLE 80-102 (CONT.)

Study Area: Carrison, North Dakota Relief: Stoniness: Parent Material:
Location. Sec. 22 Twp. 149 N Range 84 W Elevation: Soil Series:
Slope Aspect: Drainage: Soil Classification:
Climate: Vegetation: Ground Water:
Land Use: Erosion: Land Form: Profile Description By: Date:

DETERMINATION		DATA (mg/l)		LABORATORY DESCRIPTION	
Laboratory Number		16,996	16,997	Laboratory Number	14 15
Depth (Ft)		174.0 - 194.0	194.0 - 204.0	DEPTH	174.0-194.0 194.0-204.0
ALUMINUM	Al			PARTICLE SIZE ANALYSIS	(Ft) (percent)
SILVER	Ag			Very Coarse Sand	(2.0-1.0 mm)
ARSENIC	As			Coarse Sand	(1.0-0.5 mm)
BORON	B	0.3	0.7	Medium Sand	(0.5-0.25 mm)
BARIUM	Ba			Fine Sand	(0.25-0.10 mm)
BERYLLIUM	Be			Very Fine Sand	(0.10-0.05 mm)
CADMIUM	Cd			TOTAL SAND	(2.0-0.05 mm)
COBALT	Co			SILT	(0.05-0.002 mm)
CHROMIUM	Cr			CLAY	(0.002 mm)
COPPER	Cu	20.0	8.6	TEXTURAL CLASS (LAB)	(g/cm ³)
IRON	Fe			BULK DENSITY	(in/hr)
MERCURY	Hg			HYDRAULIC CONDUCTIVITY	
LITHIUM	Li			6th Hr.	
MANGANESE	Mn			24th Hr.	
MOLYBDENUM	Mo	1.6	0.2	SETTLING VOLUME	(ml)
NICKEL	Ni			MOISTURE RETENTION	(percent)
PHOSPHOROUS	P			1/10 bar	
LEAD	Pb			1/3 bar	
STRONTIUM	Sr			15 bar	23.7 14.3
SELENIUM	Se	0.0016	0.0094	SOIL REACTION-pH	9.8 9.9
SULFUR	S	200.0	53.0	Paste	7.5 7.5
ZINC	Zn			1:5 H ₂ O	
				1:2 0.01 M CaCl ₂	
				ORGANIC CARBON	(percent)
				AVAILABLE PHOSPHORUS	(ppm)
				Ca CO ₃ EQUIVALENT	(percent)
				GYPNUM REQUIREMENT	(me/100g)
				SATURATION EXTRACT	
				Saturation Percentage	
				EC _e @ 25 °C	
				Ca++	* (mmhos/cm)
				Mg++	(me/l)
				Na+	(me/l)
				K+	(me/l)
				CO ₃ -	(me/l)
				HCO ₃ -	(me/l)
				Cl-	(me/l)
				SO ₄ -	(me/l)
				NO ₃ -	(me/l)
				SAR	(me/l)
				Na	(me/100g)
				Ca+Hg	(me/100g)
				1:5 EXTRACT	
				FC _s @ 25°C	(mmhos/cm)
				Ca+Hg	(me/l)
				EXCHANGEABLE SODIUM	(percent)
				ACIDITY	
				IN KCl exchange acidity	
				Total	(me/100g)
				Al+++	(me/100g)
				CATION EXCHANGE CAPACITY	
				NaOAc@pH 8.2	25.4 11.8
				BORON	(mg/l)

* Estimated value using 3.33 x value for 1:5 extract

CEOLOGIC DRILL HOLE 80 - 103

Study Area: Carrison, North Dakota	Relief: _____	Stoniness: _____	Parent Material: _____
Location, Sec. 4 Twp. 149 N Range 84 W	Elevation: _____	Drainage: _____	Soil Series: _____
	Slope Aspect: _____	Ground Water: _____	Soil Classification: _____
Climate: _____	Vegetation: _____	Land Form: _____	Profile Description By: _____
Land Use: _____	Erosion: _____		Date: _____

DETERMINATION		DATA (mg/l)				LABORATORY DESCRIPTION				DATA			
Laboratory Number		19,698	19,699	19,700	19,701	19,702	19,703	Laboratory Number		16	17	18	20
Depth (Ft)		10.0 - 32.7	42.5 - 62.0	62.0 - 82.1	82.1 - 92.0	96.1 - 124.5	125.2 - 133.5	DEPTH	(Ft)	10.0-32.7	42.5-62.0	62.0-82.1	82.1-92.0
ALUMINUM	Al							PARTICLE SIZE ANALYSIS	(percent)				
SILVER	Ag							Very Coarse Sand	(2.0-1.0 mm)				
ARSENIC	As							Coarse Sand	(1.0-0.5 mm)				
BORON	B	0.7	1.4	1.0	1.0	0.7	1.9	Medium Sand	(0.5-0.25 mm)				
BARIUM	Ba							Fine Sand	(0.25-0.10 mm)				
BERYLLIUM	Be							Very Fine Sand	(0.10-0.05 mm)				
CADMIUM	Cd							TOTAL SAND	(2.0-0.05 mm)				
COBALT	Co							SILT	(0.05-0.002 mm)				
CHROMIUM	Cr							CLAY	(0.002 mm)				
COPPER	Cu	3.4	2.2	9.2	3.8	5.8	11.0	TEXTURAL CLASS (LAB)	(g/cm ³)				
IRON	Fe							BULK DENSITY	(in/hr)	0.11	0.07	0.00	0.00
MERCURY	Hg							HYDRAULIC CONDUCTIVITY		0.13	0.06	0.00	0.00
LITHIUM	Li							6th Hr.	(ml)	23	27	31	50
MANGANESE	Mn							SETTLING VOLUME	(percent)				
MOLYBDENUM	Mo	0.45	1.20	0.75	0.33		0.97	MOISTURE RETENTION					
NICKEL	Ni							1/10 bar		14.3	16.3	23.2	40.7
PHOSPHOROUS	P							1/3 bar					
LEAD	Pb							SOIL REACTION-PH		7.5	7.5	9.1	9.7
STRONTIUM	Sr							Paste		6.6	6.6	6.9	7.6
SELENIUM	Se	0.0139	0.0146	0.0059	0.0255		0.0057	1.5 H ₂ O					
SULFUR	S	120.0	310.0	125.0	60.0	77.0	87.0	1:2 0.01 M CaCl ₂					
ZINC	Zn							ORGANIC CARBON	(percent)				
								AVAILABLE PHOSPHORUS	(ppm)				
								Ca CO ₃ EQUIVALENT	(percent)				
								CYPSUM REQUIREMENT	(me/100g)				
								SATURATION EXTRACT					
								Saturation Percentage					
								EC@ 25 C	(mmhos/cm)	1.05	2.13	1.41	1.29
								Ca++	(me/l)				
								Mg++	(me/l)				
								Na+	(me/l)				
								K+	(me/l)				
								CO ₃ -	(me/l)				
								HCO ₃ -	(me/l)				
								Cl-	(me/l)				
								SO ₄ -	(me/l)				
								NO ₃ -	(me/l)				
								SAR	(me/l)				
								Na	(me/l)				
								Ca+Mg	(me/100g)				
								1:5 EXTRACT					
								FC@ 25°C	(mmhos/cm)	0.315	0.639	0.424	0.389
								Ca+Mg	(me/l)				
								EXCHANGEABLE SODIUM					
								ACIDITY	(percent)				
								IN RGL exchange acidity					
								- Total	(me/100g)				
								Al+++	(me/100g)				
								CATION EXCHANGE CAPACITY	(me/100g)	18.2	21.2	19.2	28.2
								NaOAc@pH 8.2	(me/100g)				
								BORON	(mg/l)				

* Estimated value using 3.33 x value for 1:5 extract

MISSOURI SOILS PROJECTS OFFICE
SOIL AND WATER LABORATORY
Bureau of Reclamation
BISMARCK, NORTH DAKOTA
SOIL ANALYSIS DATA SHEET
CEOLOGIC DRILL HOLE 80 - 103 (Cont.)

Study Area: Garrison, North Dakota Relief: Stoniness: Parent Material:
Location, Sec. 4 Twp. 149 N Range 84 W Elevation: Soil Series:
Slope Aspect: Drainage: Soil Classification:
Climate: Vegetation: Ground Water:
Land Use: Erosion: Land Form: Profile Description By: Date:

DETERMINATION		DATA (mg/l)	LABORATORY DESCRIPTION	DATA
Laboratory Number		19,704	Laboratory Number	22
Depth (Ft)		136.9 - 142.0	DEPTH (Ft)	136.9-142.0
ALUMINUM Al			PARTICLE SIZE ANALYSIS (percent)	
SILVER Ag			Very Coarse Sand (2.0-1.0 mm)	
ARSENIC As			Coarse Sand (1.0-0.5 mm)	
BORON B		0.7	Medium Sand (0.5-0.25 mm)	
BARIUM Ba			Fine Sand (0.25-0.10 mm)	
BERYLLIUM Be			Very Fine Sand (0.10-0.05 mm)	
CADMIUM Cd			TOTAL SAND (2.0-0.05 mm)	
COBALT Co			SILT (0.05-0.002 mm)	
CHROMIUM Cr			CLAY (< 0.002 mm)	
COPPER Cu		7.6	TEXTURAL CLASS (LAB)	
IRON Fe			BULK DENSITY (g/cm ³)	0.00
MERCURY Hg			HYDRAULIC CONDUCTIVITY (in/hr)	0.00
LITHIUM Li			6th Hr.	35
MANCANESE Mn			24th Hr.	
MOLYBDENUM Mo		0.83	SETTLING VOLUME (ml)	
NICKEL Ni			MOISTURE RETENTION (percent)	
PHOSPHOROUS P			1/10 bar	
LEAD Pb			1/3 bar	21.4
STRONTIUM Sr			15 bar	
SELENIUM Se		0.0026	SOIL REACTION-PH	
SULFUR S		150.0	Paste	
ZINC Zn			1:5 H ₂ O	9.6
			1:2 0.01 M CaCl ₂	7.5
			ORGANIC CARBON	
			AVAILABLE PHOSPHORUS (percent)	
			Ca CO ₃ EQUIVALENT (ppm)	
			CYPSUM REQUIREMENT (percent)	
			SATURATION EXTRACT (me/100g)	
			Saturation Percentage	
			EC _e @ 25 C	2.18
			Ca++ (mmhos/cm)	
			Mg++ (me/l)	
			Na+ (me/l)	
			K+ (me/l)	
			CO ₃ - (me/l)	
			HCO ₃ - (me/l)	
			Cl- (me/l)	
			SO ₄ - (me/l)	
			NO ₃ - (me/l)	
			SAR (me/l)	
			Na (me/l)	
			Ca+Mg (me/100g)	
			1:5 EXTRACT (mmhos/cm)	
			FC _e @ 25 C	0.655
			Ca+Mg (me/l)	
			EXCHANGEABLE SODIUM (percent)	
			ACIDITY	
			IN KCL exchange acidity	
			Total	
			Al+++ (me/100g)	
			CATION EXCHANGE CAPACITY (me/100g)	
			NaOAc@pH 8.2	12.3
			BORON (mg/l)	

* Estimated value using 3.33 x value for 1:5 extract

Criteria Used to Determine Suitability of Bedrock Material
For Use as Plant Media in Revegetation 1/

<u>Parameter</u>	<u>Methodology</u>	<u>Suitable</u>	<u>Limited Suitability</u>	<u>Unsuitable</u>
Texture	Pipette method plus sand sieving	FSL, VFSL, L, SiL, SCL	LFS, SL, CL, SiCL, SC	S, LS, SiC, C
Electrical Conductivity (mmhos/cm)	Saturation extract/conductivity bridge	< 4	4-12	>12
pH	Saturated paste/glass electrode	6.0-8.4	5.0 - 6.0; 8.4 - 9.0	5.0; 9.0
Sodium Adsorption Ratio (SAR)	Calculate: $\text{Na} / \sqrt{(\text{Ca} + \text{Mg})/2}$ Ca, Mg, and Na in meq/l	< 6	6 - 9 heavy textures 6 - 12 medium and coarse textures	> 9 - heavy textures >12 - medium and coarse textures
Exchangeable Sodium Percentage (ESP)	Ammonium acetate extraction; calculate: $\text{Na} / \text{CEC} \times 100\%$	< 5	5-15	>15 <u>2/</u>
Boron (mg/l)	Hot water extraction/carmine method	< 5		> 5
Selenium (mg/l)	Hydride generation; flameless AA	< 2		> 2
Molybdenum (mg/l)	Ammonium oxalate extraction; flameless AA or N ₂ O flame AA-5000	< 1		> 1
Copper (mg/l)	DTPA extraction; AA	<u>3/</u>		<u>3/</u>
Manganese (mg/l)	DTPA extraction; AA	< 60		> 60
Zinc (mg/l)	DTPA extraction; AA	< 40		> 40
Lead (mg/l)	DTPA extraction; AA	10-15 (pH < 6) 15-20 (pH > 6)		>15 (pH > 6) >20 (pH > 6)
Cadmium (mg/l)	DTPA extraction; AA	1		> 1
Nickel (mg/l)	DTPA extraction; AA	2-3		> 3
Mercury (mg/l)	Extraction by H ₂ SO ₄ ; flameless AA (quartz cell)	< 0.5		> 0.5
Iron (mg/l)	-		Not Established	
Nitrate-Nitrogen (mg/l)	-		Not Established	

1/ Applicable only to reclamation study areas in Montana and North Dakota

2/ Rate 2:1 - Clay texture poor if >10, sand texture if > 20.

3/ Suspect level not established - an excessive consumption of molybdenum through ingestion of vegetation may be toxic to animals. This concern is directly related to the Cu:Mo ratio in the plant tissue.

Suitability of Bedrock Material For Use As Plant Media in Revegetation -
Garrison Study Area
Drill Hole 80-101

<u>Depth (Ft)</u>	<u>Type</u>	<u>Suitability</u>	<u>Limiting Factors</u>
10.0-18.0	Sandy Clay	Limited	Texture
18.0-43.0	Sandy Clay	Limited	Texture
43.0-65.0	Sandy Clay	Limited	Texture
65.0-71.1	Sandy Clay	Limited	Texture
71.1-96.0	Sh	Limited	Texture, Molybdenum
96.0-121.0	Sh	Limited	Texture
121.0-134.5	Sh	Limited	Texture, PH, % Sodium

Legend

Ss - Sandstone	Sh - Shale
StSs - Silty Sandstone	SsSh - Sandy Shale
ShSs - Clayey Sandstone	StSh - Silty Shale
St - Siltstone	CbSh - Carbonaceous Shale
SsSt - Sandy Siltstone	Ls - Limestone
ShSt - Clayey Siltstone	SsLs - Sandy Limestone

Table 7

Sheet 2 of 3

Suitability of Bedrock Material For Use As Plant Media in Revegetation -
Garrison Study Area
Drill Hole 80-102

<u>Depth (Ft)</u>	<u>Type</u>	<u>Suitability</u>	<u>Limiting Factors</u>
10.0-35.0	Sandy Clay	Limited	Texture
35.0-54.7	Sandy Clay, Ss	Suitable	--
54.7-71.5	Sh, Ss	Suitable	--
71.5-96.0 (minus coal)	Sh	Limited	pH, % Sodium
96.0-121.0	Sh	Unsuitable	pH, % Sodium
121.0-146.0	Sh	Unsuitable	pH, % Sodium
174.0-194.0	Sh	Unsuitable	pH, % Sodium
194.0-204.5	Sh, Ss	Unsuitable	pH, % Sodium

Legend

Ss - Sandstone
StSs - Silty Sandstone
ShSs - Clayey Sandstone
St - Siltstone
SsSt - Sandy Siltstone
ShSt - Clayey Siltstone

Sh - Shale
SsSh - Sandy Shale
StSh - Silty Shale
CbSh - Carbonaceous Shale
Ls - Limestone
SsLS - Sandy Limestone

Suitability of Bedrock Material For Use As Plant Media in Revegetation -
Garrison Study Area
Drill Hole 80-103

<u>Depth (Ft)</u>	<u>Type</u>	<u>Suitability</u>	<u>Limiting Factors</u>
10.0-32.7	Sandy Clay	Limited	Texture
42.5-62.0	Sh	Limited	Texture, Molybdenum
62.0-82.1	Sh	Limited	Texture
82.1-92.0	Ss	Unsuitable	pH, % Sodium
96.1-124.5	Sh	Unsuitable	pH, % Sodium
125.2-133.5	Sh	Unsuitable	pH, % Sodium
136.9-142.0	Sh	Limited	pH, % Sodium

Legend

Ss - Sandstone	Sh - Shale
StSs - Silty Sandstone	SsSh - Sandy Shale
ShSs - Clayey Sandstone	StSh - Silty Shale
St - Siltstone	CbSh - Carbonaceous Shale
SsSt - Sandy Siltstone	Ls - Limestone
ShSt - Clayey Siltstone	SsLs - Sandy Limestone

SCREENABLE SOIL CHARACTERIZATION
AS RELATED TO
LAND RECLAMATION

By
William B. Peters, Luvern L. Resler, and Robert Vader 1/

Soil is characterized by laboratory methods to confirm judgement in field appraisals. There is a tendency among most laboratory activities to "over test"; i. e., perform too many or unnecessary tests on certain soils at the expense of not performing essential or critical testing on particular samples. Also, laboratory activities tend to emphasize comprehensive analyses of samples from master sites and neglect selection, sequence, and quality control in mass testing performed on a screenable basis. The latter-type testing is frequently handled as routine work utilizing the least dependable personnel and considered not worthy of competent and close supervision. Thus, too often the screenable laboratory testing becomes a liability rather than an asset in supporting land classification surveys. Because the screenable testing represents coverage of areas involving a high sampling density, it serves as an extremely important input into land categorization. Therefore, it should be administered for performance with respect to both quality and quantity commensurate with the goals and objectives of the investigation.

The objective of characterizing soil and overburden will be to support judgment in estimating land reclamation potential. (Overburden refers to the material consolidated or unconsolidated overlying minable resources in relation to surface mining.) Thus, the laboratory analyses must be performed on an action program basis and serve a practical purpose. Therefore, it is essential the physical and chemical characteristics of the soil and overburden be appraised in relation to edaphology; i. e., a medium suitable for the support of plant growth, rather than pedology.

Because the laboratory studies should serve to support field appraisals, all laboratory work should be closely coordinated with fieldwork. For full effectiveness, laboratory studies must be preceded by field studies. The number and type of studies will be determined by area conditions - particularly variability, the controlling project specifications, and needs. There should be a joint plan between field and laboratory investigations prior to taking of samples if maximum utilization of data is

1/ Head and Soil Scientists, respectively, Land Utilization Section, Resource Analysis Branch, Division of Planning Coordination, U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, U.S.A.

to be obtained. Problems should be studied rather than standard or routine tests made (Kellogg, 1962).

In submitting soil samples for laboratory characterizations, the laboratory should be furnished with pertinent field appraisals along with the tentative land utilization and quality designation. The soil and subsoil samples should represent genetic horizons with no more than 60-cm depth per sample. Substrata samples should represent uniform overburden with no more than 200 cm per sample unless drill hole diameters preclude obtaining sufficient material for laboratory and greenhouse studies.

The first priority in laboratory characterization should be accomplished by direct and indirect measurements for evaluating soil structure and its stability, soil-cation-exchange capacity or surface area, and soil reaction. After this is accomplished, then consideration should be given to testing that confirms, explains the causes of phenomena previously observed or predicted, reveals the presence of toxic elements (salinity level, boron content, alkali, acidity, reduction products, etc.), and indicates what and how much is required to cope with the soil deficiency under eventual field conditions and the moisture regimen expected to prevail (Peters, 1965).

Based on present knowledge of the area, the support characterizations should include field measurements for water movement and retention in soil and laboratory determinations for structure stability (Gardner, 1945) through measurements of floc volume and hydraulic conductivity of fragmented samples; moisture retentivity at 15-bars pressure; soil reaction by measurement of pH in water and neutral salt solution; soil salinity by measurement of specific electrical conductance of soil-water extracts; soil solution concentration and composition including sodium and calcium plus magnesium; cation exchange capacity; exchangeable cation status; residual gypsum; gypsum requirement; acid soluble carbonates; and others.

Samples collected in a reduced state may be alkaline or neutral while reduced, but acid when oxidized. Therefore, we should be on the "look-out" for such conditions and characteristics and assure reduced material is also analyzed in an aerated condition. Samples exhibiting acidity upon oxidation should be further analyzed to ascertain reduction products associated with the observed phenomenon.

Should conventional acidity; i. e., other than oxidation product, be encountered, the testing will be expanded to include acidity by measurement of neutral salt exchange acidity including aluminum, titratable acidity (amount of acidity neutralized at a selected pH), and soluble aluminum.

In screenable testing, the characterization for moisture retentivity at pressures less than 15 bars is not recommended unless a suitable use can be established. Measurements of moisture retentivity at 15-bars pressure are recommended because water content at this potential is usually correlated with several characteristics including amount and kind of clay, surface area, and cation exchange capacity. Moisture percentages at this potential would probably not be applicable in simulating water content at wilting for native vegetation.

In initial screening, diluted soil-water suspensions may be substituted for the time-consuming, saturated soil extracts in measuring electrical conductance provided limitations are ascertained. The reliability of higher moisture contents even as a tool in screening depends on the kind of salts present. For chloride salts, the results will be only slightly affected by the moisture content, but if sulfate or carbonate salts, which have relatively low solubility, are present in appreciable quantities, the apparent amount of soluble salt will depend on the soil-water ratio (Richards, 1954).

We do not concur in the practice of characterizing vast numbers of samples for textural class through measurements of particle-size distribution. This blanket laboratory analysis for soil textural class is neither required nor desired. Particle-size analysis should be limited to master site characterization, the occasional confirmation of field textural appraisals, and the training of new employees.

In the screenable characterization of samples, a procedure for the sequence of testing and screening of samples should encompass the following phases. Under Phase I of the scheme, all samples would be characterized for (1) soil structure stability through measurement of hydraulic conductivity on a fragmented sample basis during the 6th and 24th hours and volume of wet settled floccules, (2) moisture retentivity at 15-bars pressure, (3) electrical conductivity of soil-water extract, and (4) pH in water and in 0.01 molar calcium chloride solution.

In the second phase, selected samples suspected through the testing results of Phase I to be salt affected should be characterized for electrical conductivity of the saturation extract and sodium adsorption ratio.

In the third phase, selected samples suspected through the testing results of Phases I and II to be salt affected with respect to sodium will be tested for either gypsum requirement or residual gypsum, depending on salinity levels and associated pH values. Residual gypsum will be estimated by measuring calcium plus magnesium in a 1:5 soil-water ratio extract and reported in milliequivalents per 100 grams.

In the fourth phase, selected samples suspected through testing results of Phase 1 to be highly acid and low in base saturation and nonsaline should be further characterized for bases specifically sodium and calcium plus magnesium and acidity including the aluminum component extractable with a neutral salt; i. e., 1.0N potassium chloride. This will enable computation of effective soil-cation-exchange capacity; i. e., CEC at soil pH and the exchangeable aluminum percentage of this CEC.

In the fifth phase, selected samples having been characterized during Phases 1, 11, and 1V to be saline acid would be characterized for soluble aluminum.

The above-described characterization program would not preclude testing on a "complete analysis" basis on samples from master sites.

Soils & Water Laboratory Procedures and References

I. Soil Characterization

A. Physical Properties of Soils

1. Disturbed Hydraulic Conductivity is determined by the use of Plastic tubes (Richards, et al., 1954, Diagnosis and Improvements of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 34b:112-113).
2. Settling Volume, Imhoff Cones, (Series 510 Land Classification Techniques and Standards 517.5.7).
3. Particle Size Analyses are determined by pipeting and analysis (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 41:122-123).
4. Particle Density, (C. A. Black, et al., Methods of Soil Analysis Part 1, Agronomy No. 9, American Society of Agronomy, 29:371-373), Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 39:122).
5. Bulk Density, (C. A. Black, et al., Methods of Soil Analysis Part 1, Agronomy No. 9, American Society of Agronomy, 30-1:374-390), (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 38:121-122).
6. Moisture Retention in Laboratory is determined by ceramic plates (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 29, 30 and 31:109-110).
7. Field Capacity - field determination.
8. Water holding capacity - determined by calculation: field capacity-wilting point x bulk density x 48 inches = water holding capacity per 48 inches of soil.

B. Soluble Cations and Anions

1. Carbonates and bicarbonates are determined with automated Fisher titralyzer II by acid titration and chlorides are determined with automated Fisher titralyzer II, Specific Ion (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 82:145-146 and 84:146), C. A. Black, et al., Methods of Soil Analysis, Part 2, Agronomy No. 9, American Society of Agronomy 62-3.4.1:945-947 and 62-3.5.1:947-948, (M. J. Taras, et al., Standard Methods for the Examination of Water and

Wastewater; Thirteenth Edition, for carbonate and bicarbonate only 102:52-56), (Bear, et al., Chemical of Soils, 1964), and (Brown, Skougstad and Fishman, Techniques of Water Resources Investigation of USGS, Chapter AI, "Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases," Book 5 - Laboratory analysis for chloride only, p. 69).

2. Phosphorus soluble in sodium bicarbonate and Automated Ascorbic Acid (C. A. Black, et al., Methods of Soil Analysis, Part 2, Agronomy No. 9, American Society of Agronomy 73-4.4:1044-1049), (EPA Methods for Chemical Analysis of Water and Wastes, 1979 EPA-600 4-79-020, 365.1:365.1-1-365.1-9).
3. Nitrate-Nitrite are determined by phenoldisulfonic acid and by Automated cadmium reduction (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, Part 2, Agronomy No. 9, American Society of Agronomy 84.5.3:1216-1219) and (M. J. Taras, et al., Standard Methods for the Examination of Water and Wastewater, 1971 Thirteenth Edition, 133:233-237) Methods for Chemical Analysis of Water and Wastes, 1979 EPA-600 4-79-020, 353.2:353.2-1-353.2-7.
4. Sulfate is determined by Automated Methyl Thymol Blue and turbidimetric, (EPA Methods for Chemical Analysis of Water and Wastes, 1979 EPA-600 4-79-020, 375.2:375.2-1-375.2-4), (M. J. Taras, et al., Standard Methods for the Examination of Water and Wastewater, 1971 Thirteenth Edition, 156C: 334-336).
5. Sodium, Potassium, Calcium and Manganese are determined by Automated atomic absorption (Perkin-Elmer, Analytical Method for Atomic Absorption Spectrophotometry, 1973), and (Brown, Skougstad and Fishman, Techniques of Water Resources Investigation of USGS, Chapter AI, "Methods of Collection and Analysis of Water Samples for Dissolved Minerals and Gases," Book 5 - Laboratory Analysis, 66, 109, 133 and 143).

C. Trace Metals

1. Trace Metals are determined by atomic absorption with flame or graphite furnace (Perkin-Elmer, Analytical Method for Atomic Absorption Spectrophotometry, 1973), (Brown, Skougstad and Fishman, Techniques of Water Resources Investigation of USGS, Chapter AI, "Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases", Book 5 - Laboratory Analysis, 50-157) and M. J. Taras, et al., Standard Methods for the Examination of Water and Wastewater, 1971 Thirteenth Edition), Methods for Chemical Analysis of Water and Wastes, 1979 EPA-600-4-79-020, DTPA-TEA extraction for Cu, Fe, Mn, and Zn, University of Montana, Missoula, Montana.

D. Chemical Soil Characterization

1. pH reading of 1:5 Soil Suspension (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 21b:102) (C. A. Black, et al., Methods of Soil Analysis, Part 2 Agronomy No. 9, American Society of Agronomy 60-3.4:922-923) and (Bear, et al., Chemical of Soils, 1964).
2. pH reading in CaCl_2 Solution (C. A. Black, et al., Methods of Soil Analysis, Part 2, Agronomy No. 9, American Society of Agronomy 60-3.5:923).
3. Saturation Extract taken from saturated soil paste using Bariod filter press and measuring soluble salts by use of electrode conductivity bridge (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 6, 2 and 3:84-88, 27:107 and 4:89-90). C. A. Black, et al., Methods of Soil Analysis, part 2, Agronomy No. 9, American Society of Agronomy 62-1:933-988) and (Bear, et al., Chemical of Soils, 1964).
4. Exchangeable Sodium and Potassium are extracted by ammonium acetate solution. Cation-Exchange Capacity determined using Sodium Acetate as index ion and follow with Ammonium Acetate (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 18:100-101 and 19:101) and (C. A. Black, et al., Methods of Soil Analysis, Part 2, Agronomy No. 9, American Society of Agronomy 72-3:1033, 72-3.2.1:1033-1034 and 57-1:891-895).
5. Exchangeable Sodium Percentage is determined by calculation relationship being $\frac{\text{Na}}{\text{CEC}} \times 100$ (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 20a:101).
6. Gypsum determined by increase in soluble calcium plus magnesium content upon dilution (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 22c:104).
7. Gypsum Requirement (Richards, et al., 1954, Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60, 22d:104-105).
8. Boron was determined by extraction with hot water (C. A. Black, et al., Methods of Soil Analysis, Part 3, Agronomy No. 9, American Society of Agronomy 75-4:1062-1063 and 62-3.6 949-951).

9. Percent Organic Carbon is determined with Technicon Auto Analyzer II.
10. Total Carbonates expressed as % calcium carbonate, acid-neutralization, (C. A. Black, et al., Methods of Soil Analysis Part 2, Agronomy No. 9, American Society of Agronomy, 91-4:1387-1388), (Richards et al., 1954 Diagnosis and Improvement of Saline and Alkali Soils USDA Agriculture Handbook No. 60, 23c:105-106).
11. SAR (sodium adsorption ratio) determined by calculation:
$$\text{SAR} = \text{Na} / \sqrt{\text{Ca} + \text{Mg}/2}.$$

Bureau of Land Management
Library
Bldg. 50, Denver Federal Center
Denver, CO 80225

[illegible]

BLM LIBRARY -
SC-324A, BLDG. 50
DENVER FEDERAL CENTER
P. O. BOX 25047
DENVER, CO 80225-0047

DATE DUE

GAYLORD

PRINTED IN U.S.A.

